



National Aeronautics and
Space Administration



CubeSats and Science Return

The National Academies' Meeting on
Achieving Science Goals with CubeSats
September 2-3, 2015

Dr. David Korsmeyer
Director of Engineering
NASA Ames Research Center



National Aeronautics and
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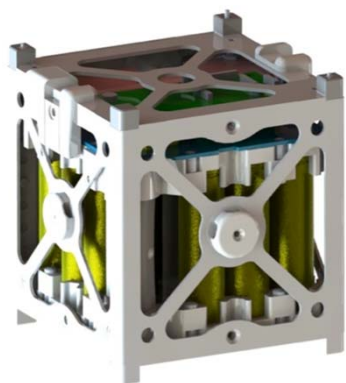


CubeSats (aka canisterized Nanosats)

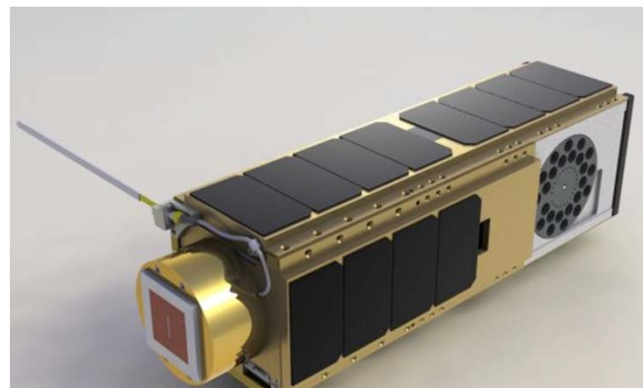
- Started as a University standard for teaching satellite design at Stanford University and Cal Poly University
- 10 X 10 X 10cm Cube as a Standard form factor = 1U
- Weighing 1-2 kgs for each 1U of volume

Common Form Factors

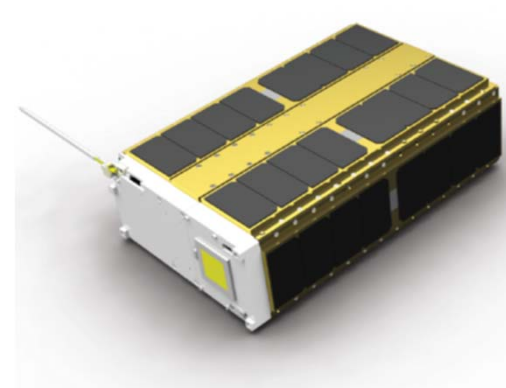
1U



3U



6U





NASA Ames' CubeSat Missions

NASA Ames has the oldest NASA effort in CubeSats

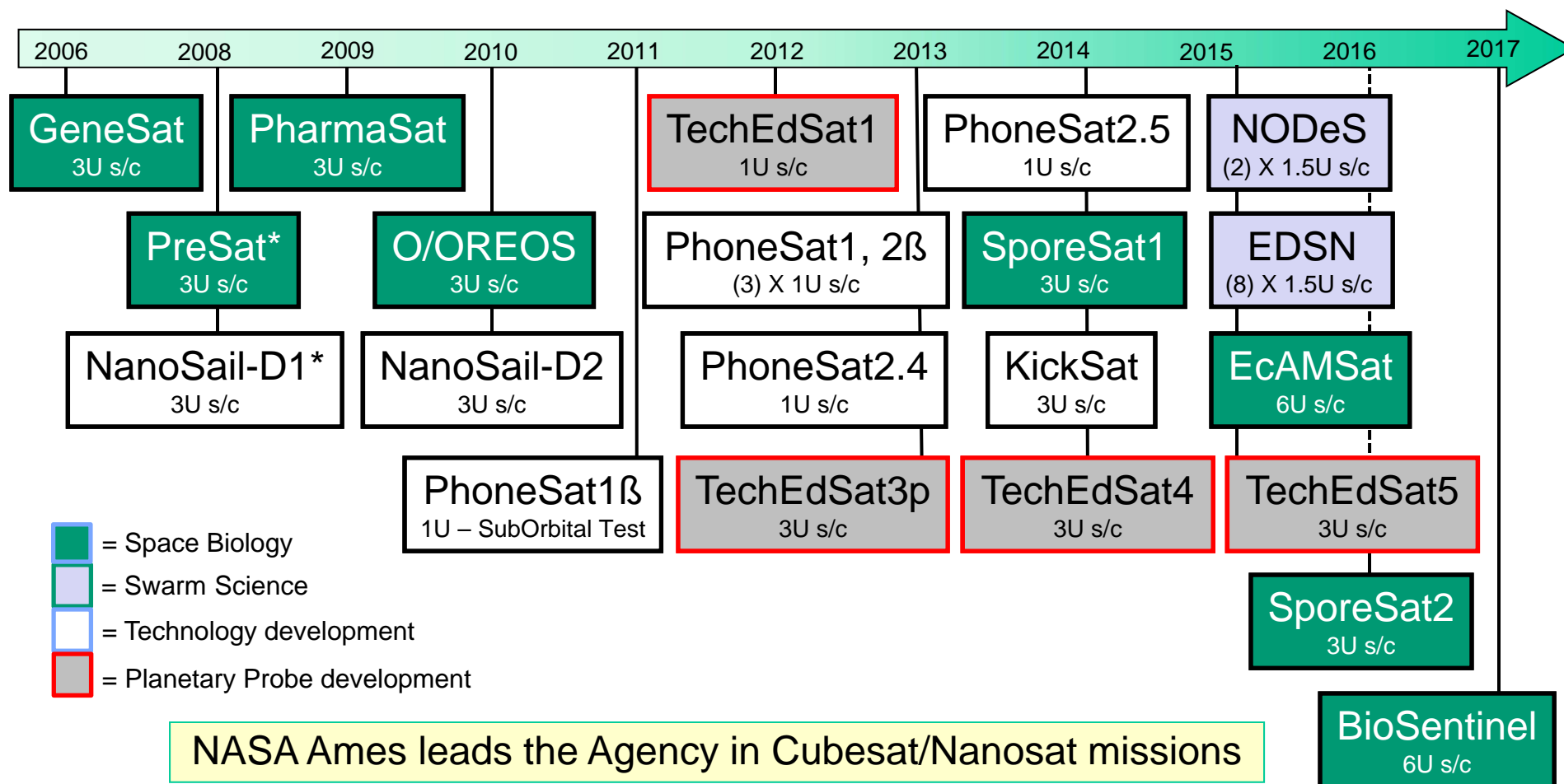
- Peer-review Science with its CubeSat Missions since 2006
- 21 Mission flown (31 CubeSats) or in active development
- Deployed NASA's first 1U and 3U CubeSats from ISS (2012, '14)
- Developed the first CubeSat Science Swarms (Oct 2015, '16)
- Developing the first Beyond LEO Bio-nanosat (Biosentinal 2018)

Ames CubeSats have been supporting the goals of:

- Space Biology Science,
- Swarm Science, and
- Technology Development.



NASA Ames' CubeSat Missions





Fundamental Space Biology CubeSat pathfinders

2005-2009 Bio-CubeSat technology demonstration missions were a joint effort of:

- NASA Ames Research Center
- San Jose State University,
- Santa Clara University,
- Cal Polytechnic University,
- Utah State's Space Systems Development Laboratory,
- National Center for Space Biological Technologies of Stanford University.

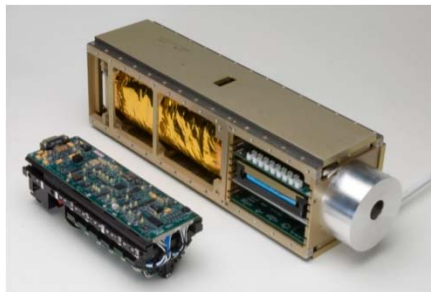
GeneSat



Objective:

To study the effects of the microgravity environment on biological cultures (bacteria, genetic and biological probes to detect "gene expression")

Launched Dec 2006



PI: Tony Ricco, Stanford University
Engineering: NASA Ames Research Center

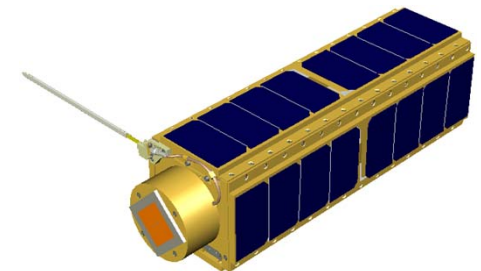
PharmaSat



Objective:

Biological payload to measure the influence of microgravity upon yeast resistance to an antifungal agent.

Launched 2009



PI: Michael McGinnis, Univ of Texas, Med Branch
Engineering: NASA Ames Research Center



NASA's Astrobiology Program

The Astrobiology Program is managed by the Planetary Science Division of the Science Mission Directorate at NASA Headquarters. Ms. Mary Voytek is the Senior Scientist for Astrobiology in the Planetary Science Division.

NASA established the Astrobiology Program in 1996, but has been studying it since the beginning of the US Space Program.

*NASA's Astrobiology Program addresses three fundamental questions:
How does life begin and evolve? Is there life beyond Earth and, if so,
how can we detect it? What is the future of life on Earth and in the
universe?*



NASA's Space Life and Physical Science (SLPS)

NASA's Human Exploration and Operations Mission Directorate (HEOMD) support the Agency's efforts in Space Life and Physical Sciences (SPLS) Division. Dr. Marshall Porterfield is the Division Director.

NASA Ames hosts the Space Biology Program of the SLPS Office. Ms. Nicole Rayl is the Program Manager

Space Biology's goal is to perform peer-reviewed biological research and development on ISS and Nanosats necessary to understand how life operates in Space. The goal is to enable NASA's long-term human exploration missions and also benefit life on Earth.

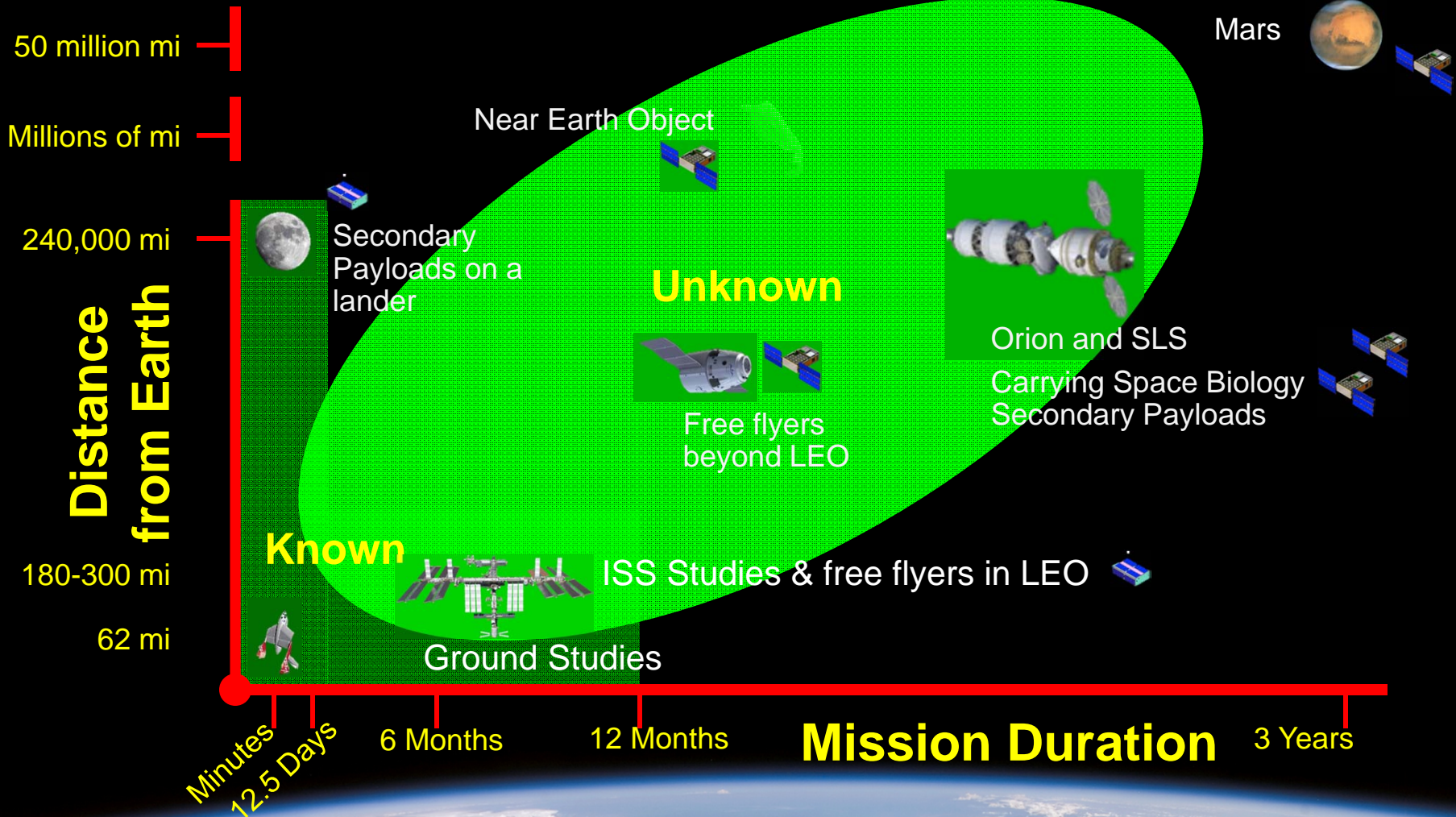


Space Biology Motivation

- The limit of complex life in space, as we know it, is 12.5 days on a lunar round trip and ~1 year in LEO.
- As we send people further into space, we have to use other organisms to understand the biological risks and how they can be addressed.

Beyond

Mars





National Aeronautics and
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Ames

Discovery • Innovations • Solutions



Space Biology Nanosats: *Testing Life in Space*

Genesat thru PharmaSat

- 3U Cubesats, launched 2006 through May 2009, full mission success, 2U Biology payloads
- PS Grew & characterized **yeast (*S. cerevisiae*)**; tracked metabolic activity in 48 μ wells

O/OREOS

- 3U Cubesat, launched November 2010, full mission success, 2 payloads
- Demo'd satellite bus & payload instrument functionality > 3.5 years in high-rad 15x ISS

SporeSat 1 & SporeSat 2 (ISS deployed)

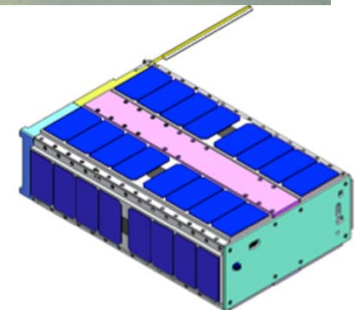
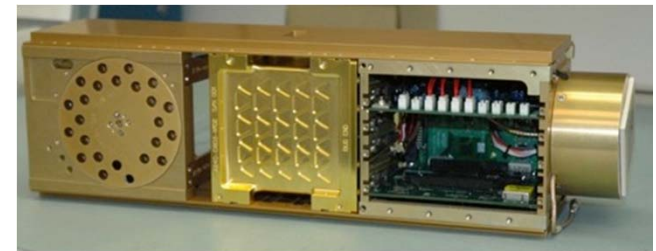
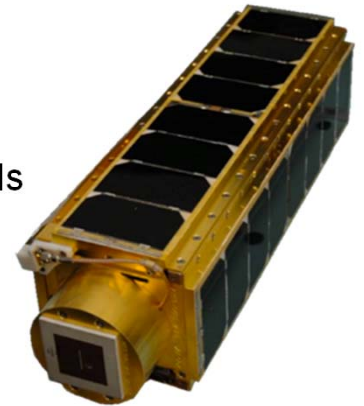
- 3U Cubesat, launched April 2014, 2nd spacecraft in Spring 2016
- Demonstrated growth of spores in gel medium, in variable-g

EcAMSat

- 6U Cubesat, launch ~ Fall 2015, 3U Biology payload
- Demonstrating *e Coli* antimicrobial resistance changes due to radiation and μ gravity

BioSentinel (The First Deep Space Bio Experiment)

- 6U Cubesat, launch ~ Fall 2018 on a Lunar mission, 4U Biology payload
- DNA damage and repair in **yeast (*S. cerevisiae*)**; tracked metabolic activity
- Demonstrate use of simple organisms as “biosentinels” to Inform of risks to humans beyond LEO





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Ames
Discovery • Innovations • Solutions



EDSNs: *Swarm Technology Demonstrators*

NASA STMD's Small Spacecraft Tech Program has funded the development of Enabling Technologies for CubeSats

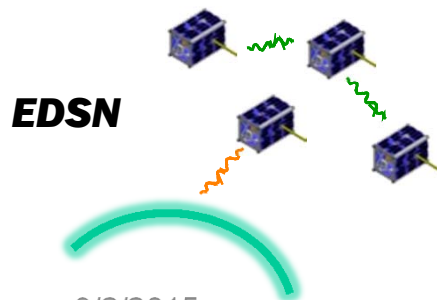
EDSN: Edison Demonstration of Smallsat Networks

- 8 x 1.5U CubeSats, First Nanosat Swarm
- Multipoint synchronous measurements of upper atmosphere
- EDSN Swarm satellites using consumer-grade components
- Single downlink by Swarm Captain, Crosslinks with other spacecraft

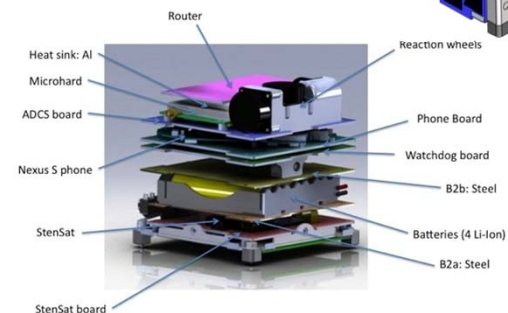
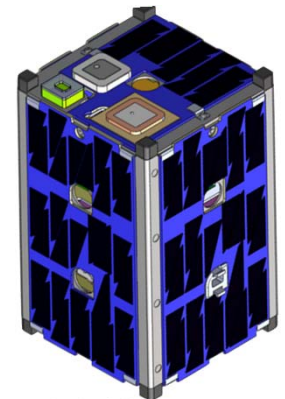


NODES: Network Operations Demonstration Satellite

- 2 x 1.5U CubSats
- EDSN Nanosats with Advanced Software deploying off of ISS
- Negotiated Captaincy of Swarm between Satellites
- Multipoint synchronous measurements of upper atmosphere



- NASA Ames – PM and S/C bus
- PI: Dr. David Klumppar -Montana State University
- Santa Clara University – Ground Station



9/2/2015

CubeSats and Science Return

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CubeSats are a Disruptive change...





Why are CubeSats popular (and disruptive)?

1. Canisterized payload makes launching easier
 - Interface Requirements dictated mostly by dispenser and LV orbit
 - US Government sponsors launches for Educational and Non-Profits (CLSI)
 - Commercially available (SpaceFlight Services, TriSept, Nanoracks, etc)
2. Cost of Entry into CubeSat development is very low
 - A basic “sputnik” hardware can be purchased for \$10k’s.
 - Mass and size limits help bound the costs of the system
3. Fixed-size has provided a viable market for common components
 - Universities can Design, Build, Operate basic LEO Space science missions.
 - Comm originally used Ham-band and UHF radio for easy downlink reception without expensive specialized hardware
4. Student/Professional Life-Cycle Engagement
 - Life-cycle of mission can be achieved in a Student’s academic (or a young professional’s) career. Concept to Operations (18 – 36 months)
5. Low-Cost of Failure
 - Minimal prescriptions for project management (review, and documentation)
 - Implies limited required engineering and testing rigor



Growing Gov't support for CubeSat Science

NASA Ames Research Center started flying CubeSats for Space Biology payloads in 2006.

NSF Cubesat Program: CubeSat-based science missions for Geospace and atmospheric research. Program conceived 2007; first solicitation 2008. Space weather & atmospheric research and education. STEM and LEO-based Science. (POC: Dr. Therese Moretto Jorgensen)

USAF/AFRL's University Nanosat Program: A joint program between the Air Force Research Laboratory and the Air Force Office of Scientific Research (AFOSR). Supporting workforce development, technology development, and sustainment of space science research at US universities. Started in 1999 and now largely CubeSats. (POC: Dr. David Voss)

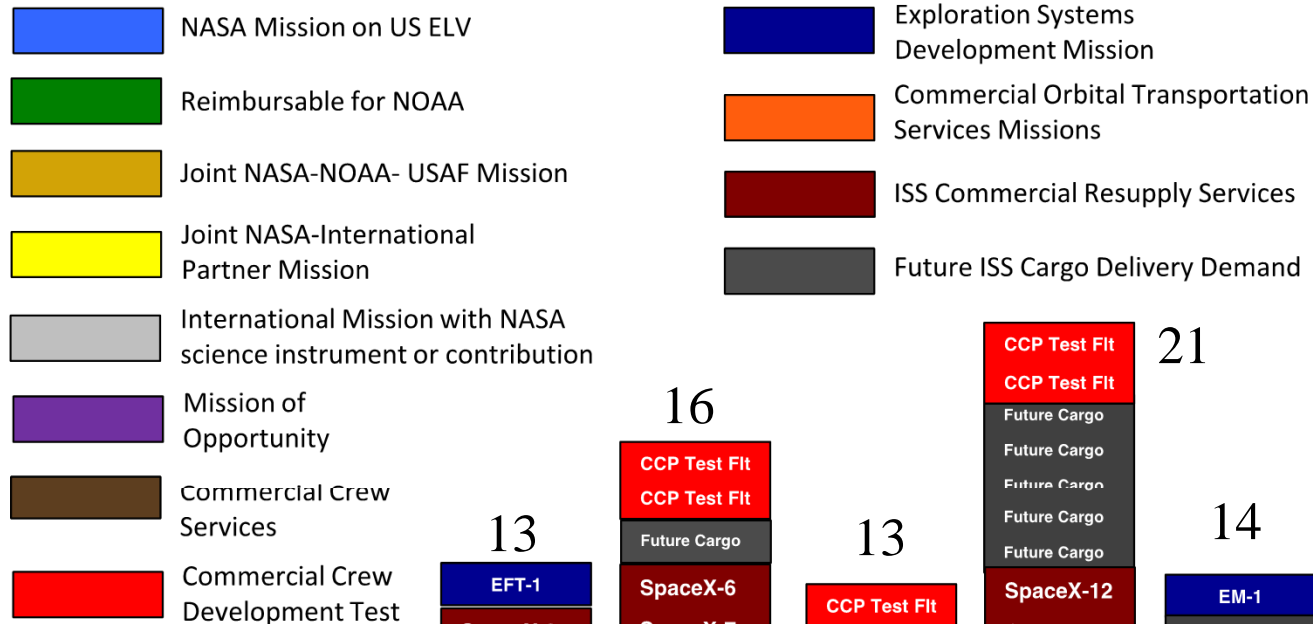
NASA's CubeSat Launch Initiative: NASA Launch Services created in 2010 to provide access to space for CubeSats developed by educational institutions and non-profit organizations, as auxiliary payloads on NASA rocket launches or ISS. (POC: Mr. Jason Crusan)

NASA's Small Spacecraft Technology Program: Started in 2011 by the Space Technology Mission Directorate. Has competitively selected CubeSat missions, Awarded University partnerships, supports the CubeQuest Challenge Competition. (POC: Mr. Andy Petro)

NASA's Science Mission Directorate: Started in 2013 with Research Announcements (ROSES, ESTO/InVEST, H-TIDES, APRA, SIMPLEX) and SALMON and Earth Venture opportunities. (POC: Mr. David Pierce)



NASA Mission Launches (Fiscal Years 2013 – 2020)



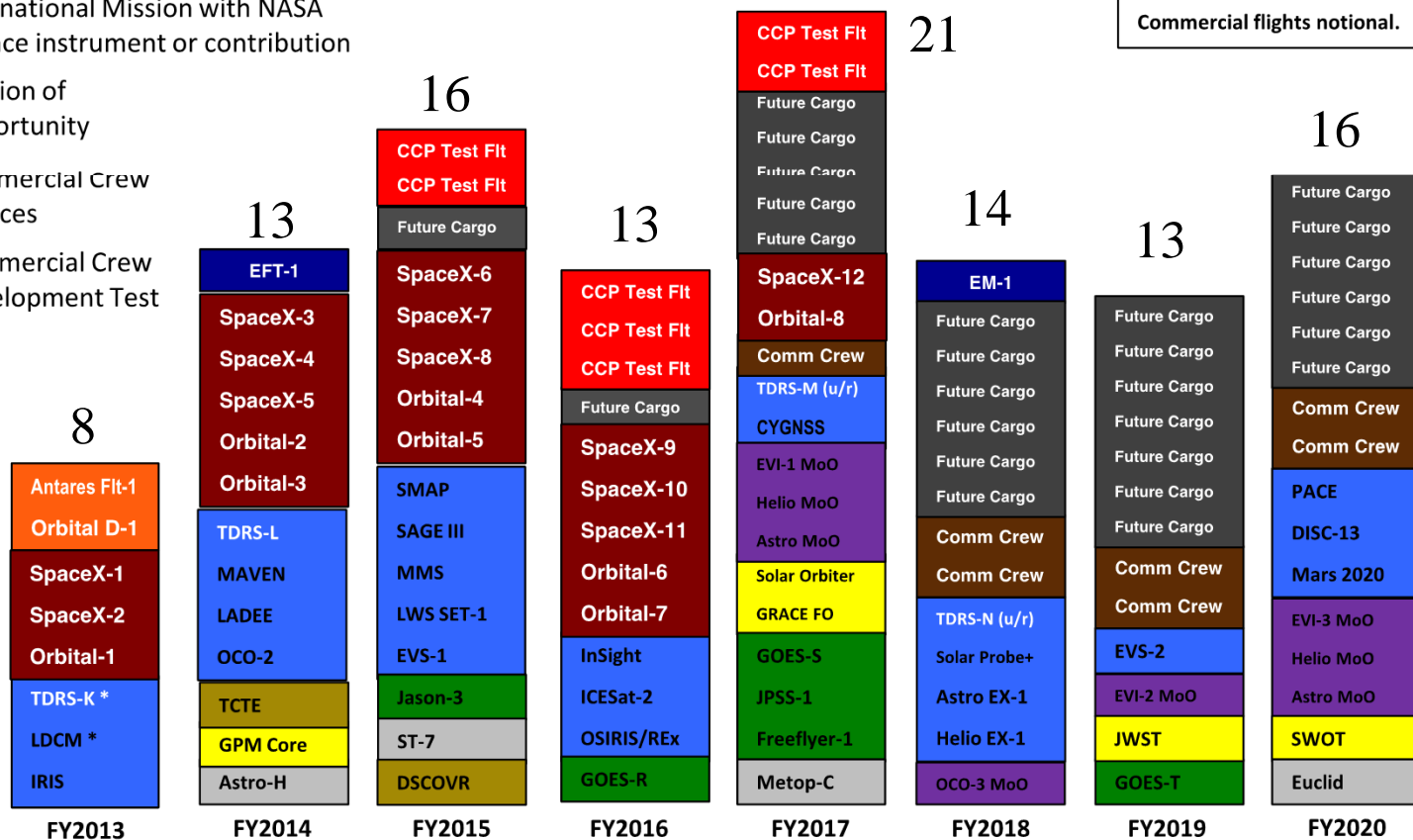
Limited NASA Launch Opportunities each year

HEO missions denoted in white text.

SMD missions denoted in black text.

International launches not shown.

Commercial flights notional.

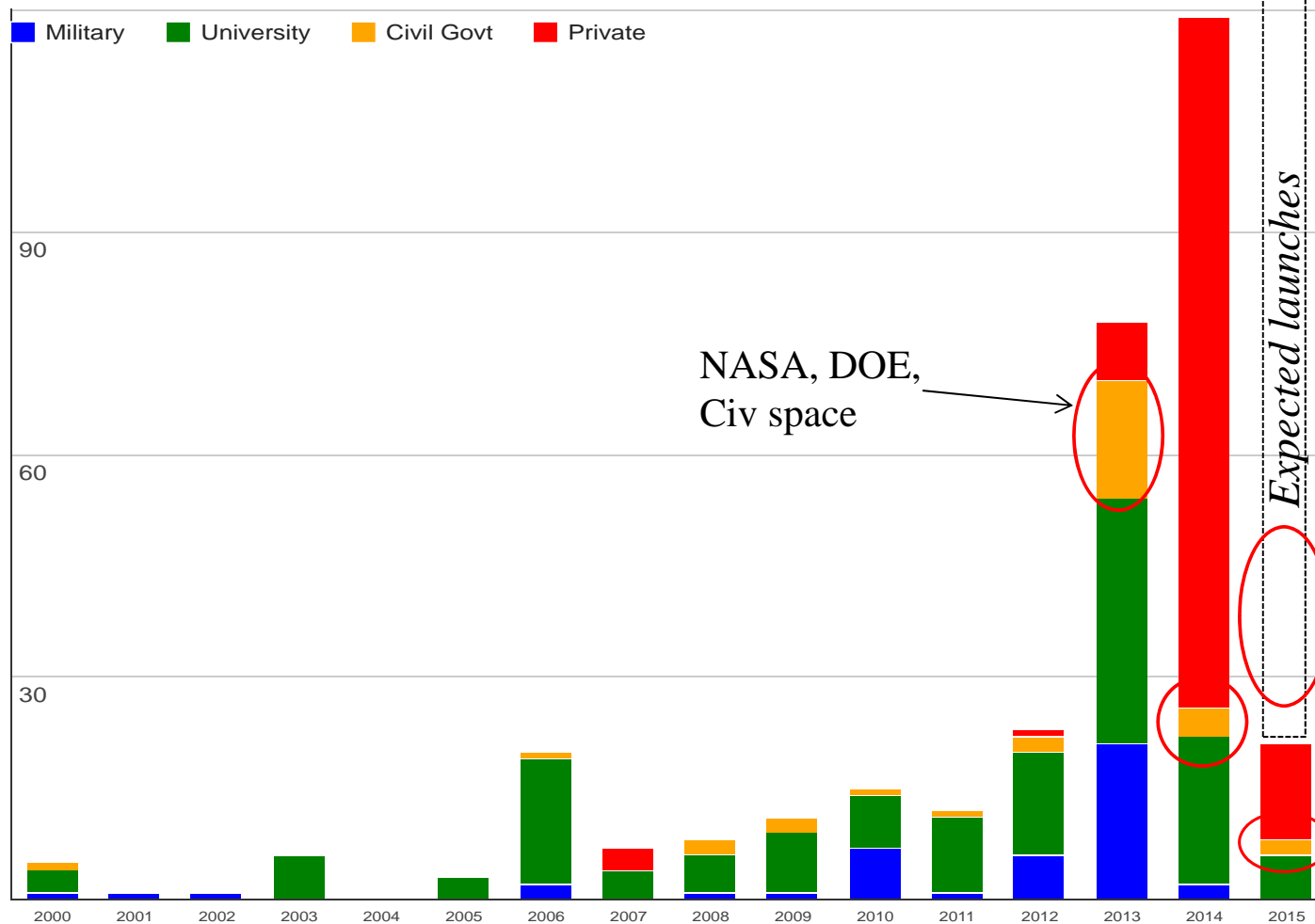




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CubeSat Launch Cadence increases



[Chart created on Sat Apr 25 2015 using data from M. Swartwout]



Challenges for CubeSats and Science Return...

CubeSats have unique challenges due to their size, mass and cost targets

1. Traditional Space Science instruments expect good bandwidth comm (>10kbs), high power (>10Ws), good pointing, propulsion to the desire orbits, and on-board automation capabilities.
 - CubeSats provide tight Size, Weight, and Power constraints for the instruments.
 - Designing a very small low-power, low-bandwidth instrument can be costly and difficult
2. Non-recurring Engineering efforts don't scale with CubeSat size and mass
 - To design a reliable Spacecraft requires good engineering staff. Fractional people don't support flight projects well.
 - Software development is critical for CubeSats, but that can be very expensive compared to the hardware costs.
3. Size and cost are correlated, but not causally linked. Small can be cheap, but it also can be very expensive.



What are the Capabilities of CubeSats?

- CubeSats can largely do the same missions that traditional satellites could do in the 1960s
- CubeSats form-factor and launch constraints bound what instruments can be flown, but not what clever science can be delivered.
- As CubeSats become more capable they begin to encroach on Science return that larger Missions used to provide.
 - This is good for Science, but will change the economics of Organizations that provide larger missions.
 - Larger missions will need to be more unique and have more rigorous requirements



Technologies Needed for Robust CubeSat-based Science exploration

Turning CubeSats into fully-functional Nanospacecraft needs improvements in “C3PO”

C3PO for CubeSats is

- **Communications:** Higher bandwidth, long distance comm
- **Power:** Reliable, multi-10Ws of power
- **Propulsion:** 100m/s – 1km/s
- **Pointing:** Arcsecond control, and rapid slewing
- **Operations:** Autonomous GN&C, Mission Ops

Enhancements in each of these Areas is required for CubeSats to be true nanospacecraft



Policy-related constraints on the CubeSats?

- There are several Policy-centric issues that need to be addressed as the prevalence of CubeSats increases;
- Lifetime, End-of-life and De-orbit agreements.
 - We don't want CubeSats to be "space debris". So in LEO they must either be in fast entry orbits, or have a de-orbit capability
 - Outside of LEO, CubeSats need to have long-term beacon's or be de/re-orbited.
- Communications
 - Traditional Space Comm architectures are too cumbersome and expensive for CubeSats.
 - Consider Iridium, GlobalStar etc for Comm. What are Command & Control guidelines for commercial comm systems?



CubeSat's Value Proposition: High ROI

Mission Concepts to Space Results in 18-36 months

- Frequent access to LEO space (thru CLSI, etc)
- Rapid development of missions
- Comparatively low-cost s/c hardware
- Reflight of same hardware in 9-12 months
 - Mitigates the Risks of failure

Science Opportunities Exist on small budgets if the Science investigation matches the constraints



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CubeSats and Science Return

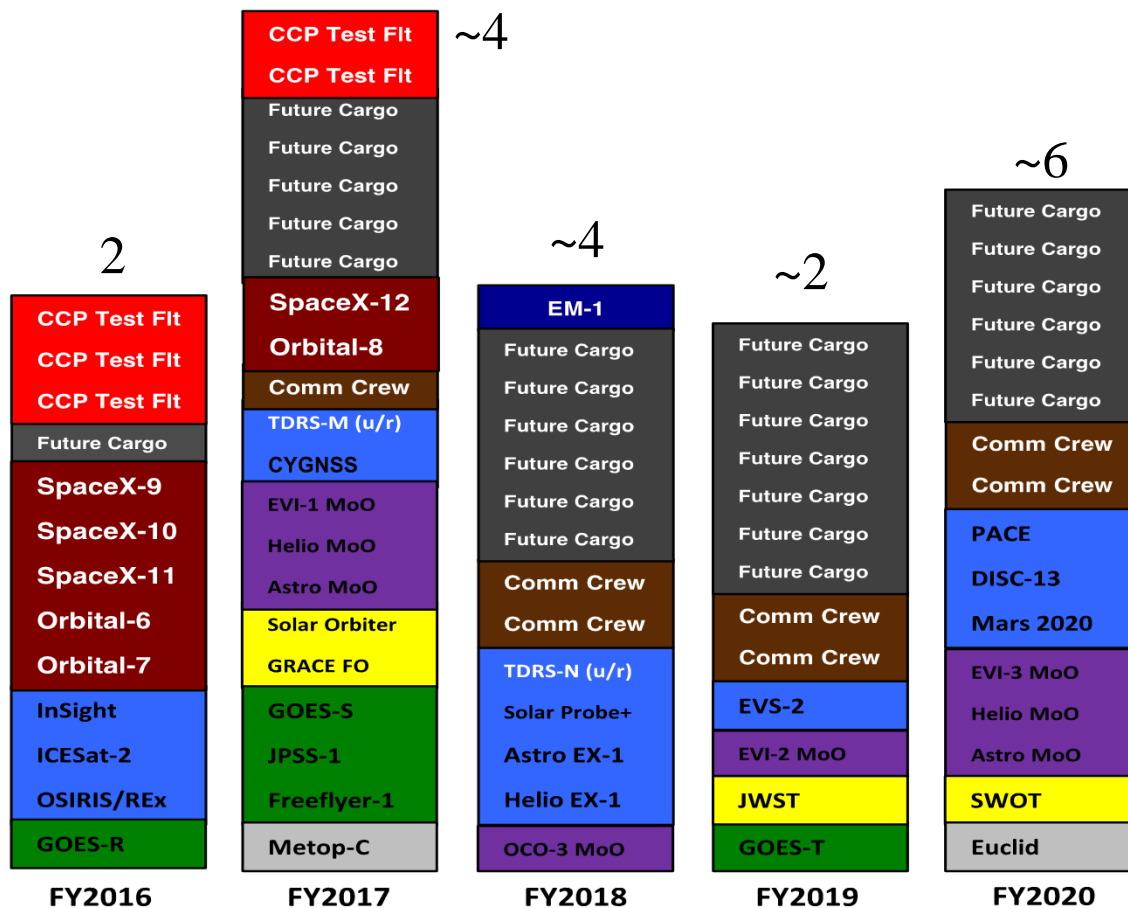


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Science Beyond LEO

NASA's Deep Space ($C3 > 0$) launches are few. How can we gain more access to Deep Space?





New Opportunities for Space-based Science

There are two ways that NASA can use CubeSat/Nanospacecraft for larger-scale Space-based Science exploration.

- **Alternatives to Traditional Missions:**

For Example:

- Deploying a Swarm of Science CubeSats in LEO instead of a larger spacecraft
- Leveraging the Secondary Launch Market to get deployed in LEO/GEO

- **Augmentations to Traditional Missions**

For Example:

- Developing complementary CubeSats to launch with a larger spacecraft mission
- Deploying during the main mission as a component of the overall objectives



Small-scale systems for broader Planetary Exploration:

*Maximize Interplanetary Missions with CubeSats as
Secondary payloads on larger NASA missions*

Example Significant Mission Opportunities:

- SLS's Cislunar Flights – EM-1, EM-X
- Mars Missions – InSight, Mars 2020, Mars 2024/26
- Secondaries on future Discovery & New Frontiers Missions
- Secondaries on Asteroid Rendezvous Mission (ARM)
- Secondaries on Europa Clipper



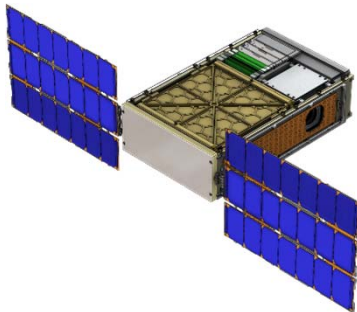
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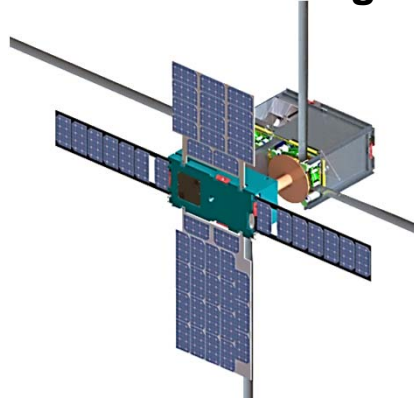
HEO's Advance Exploration Systems EM-1 Secondary Nanospacecraft



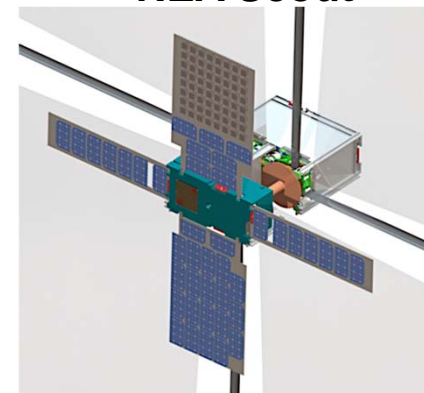
BioSentinel



Lunar Flashlight



NEA Scout



- Three 6U NanoSpacecraft (aka Cubesats) were selected to fly on the EM-1 Mission as Secondary missions
- The Space Launch System deploy these Secondaries after the Orion capsule separates
- Each Nanospacecraft has defined Science objectives

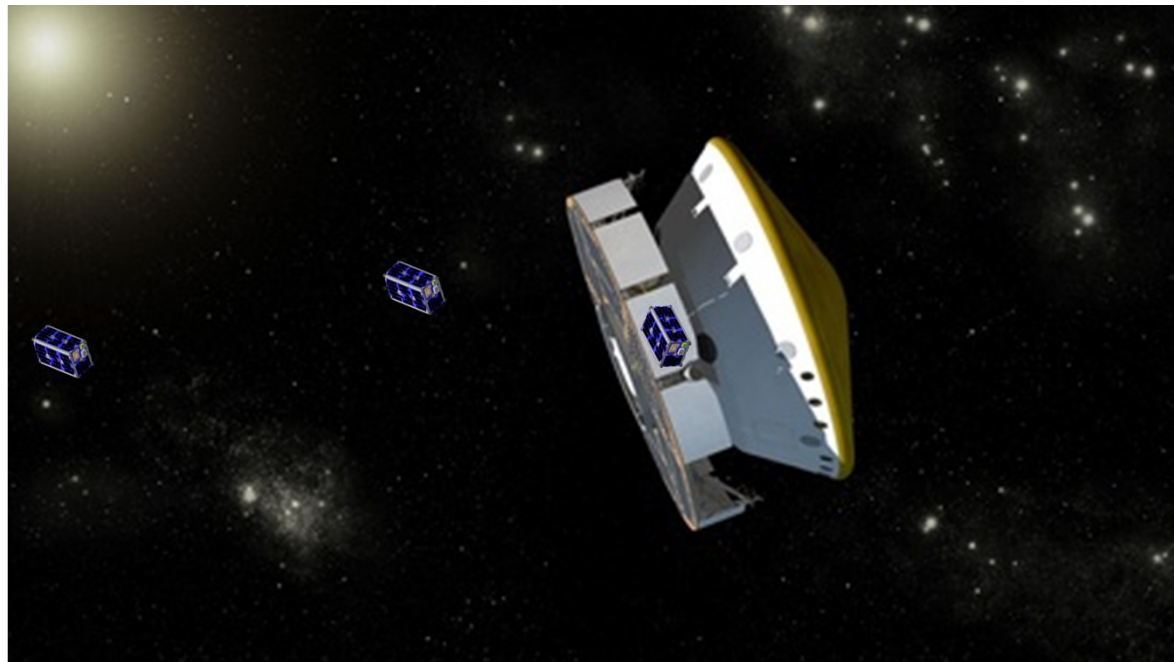


CubeSats as Deep Space 'Buoys'

Space Weather and long-term bioscience payloads in a constellation of Nanospacecraft 'Buoys'

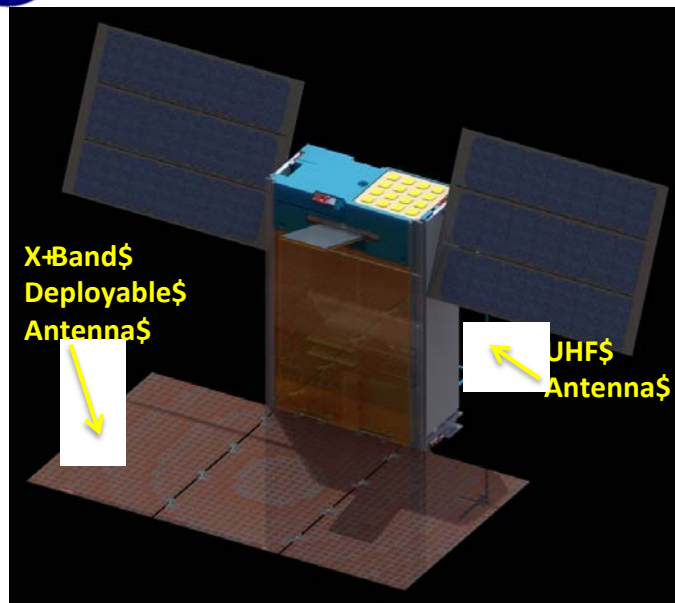
- E.g. Deployed from a Mars transfer stage or spacecraft during the cruise between Earth and Mars orbit.

Augmenting the main mission by targeting Phobos, Deimos, or the Martian Surface





Mars Cube One **First Planetary CubeSat Mission**

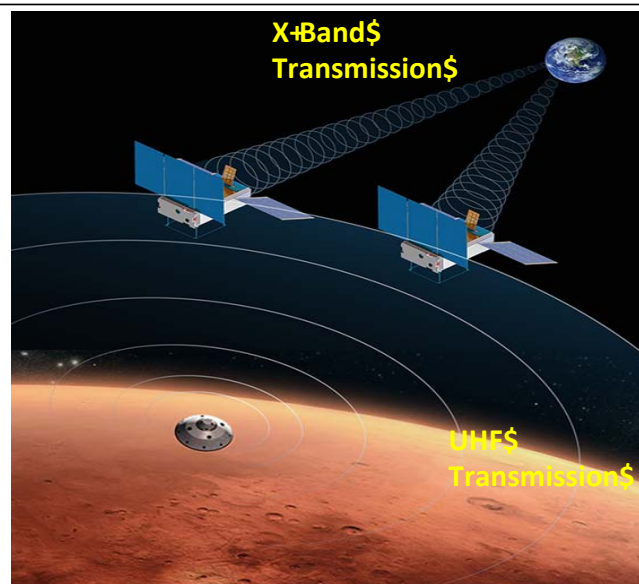


A Technology Demonstration of communications relay system for mission-critical events such as the 2016 InSight entry, descent, & landing.

*Interplanetary Travel
Fly-by Mars*

Note: MarCo is not a Science mission, but a technology demonstration and mission augmentation.

- Two redundant 6U CubeSat form factor
- Launch: Mar. 2016; Arrival: Sep. 2016
- Real-time relay of InSight EDL data
 - 8 kbps UHF link: InSight to MarCO
 - 8 kbps X-band link: MarCO to DSN



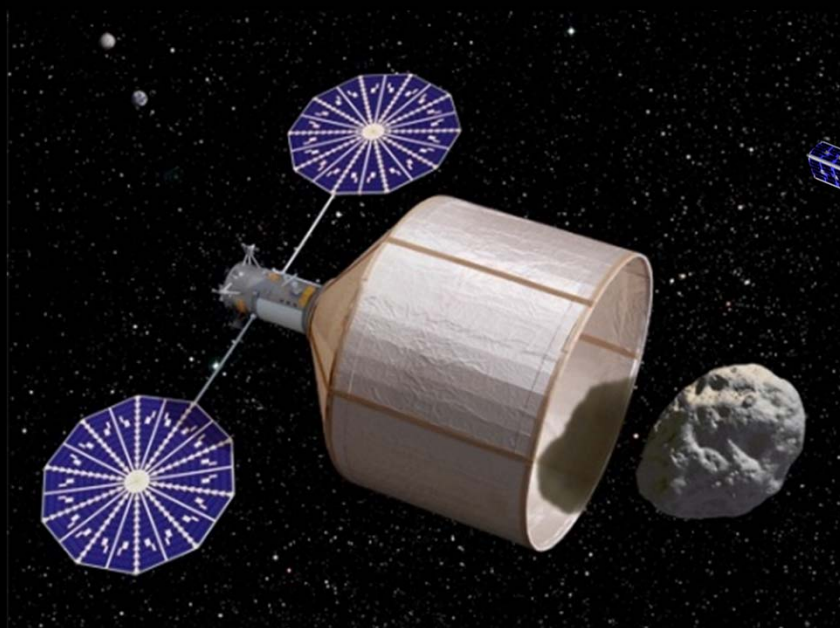
It does showcase the potential for CubeSats as platforms for independent science gathering at planetary bodies.



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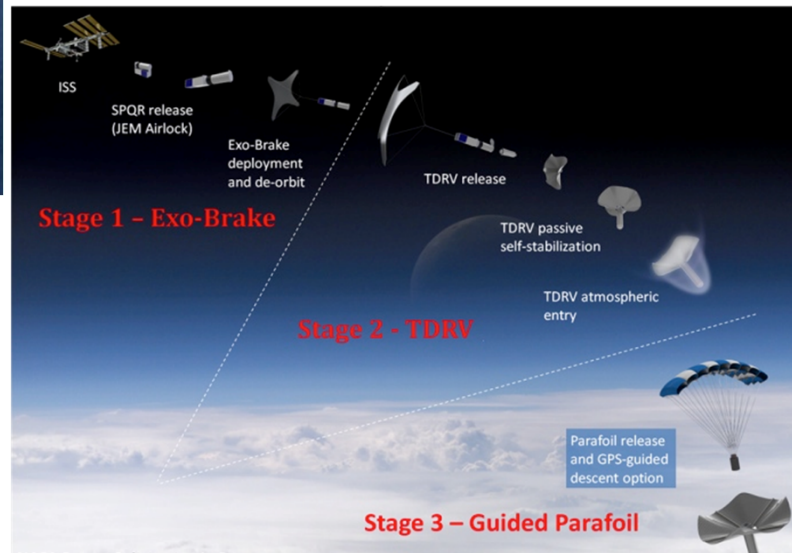


'Escorts' for the Big Exploration missions (ARM?)

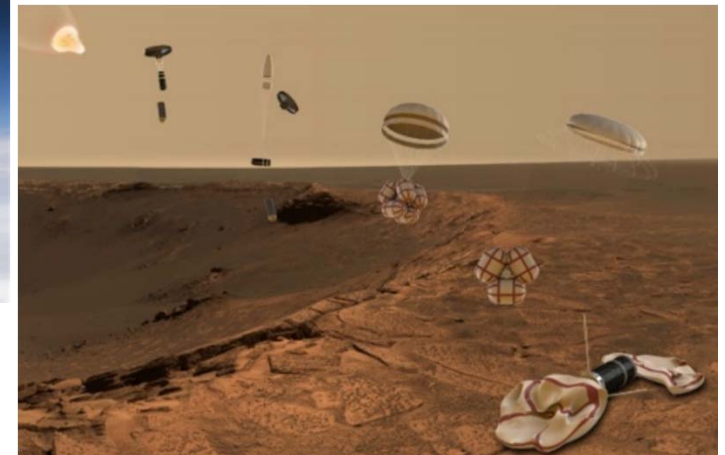


Planetary Nanosat Probes

Demonstrating from ISS
For Earth Atmospheric Probes



Mars/Venus probes



Planetary Nanosats with applications to Mars and planetary
surface Missions



What types of Unique Science Missions/Operations can CubeSats enable?

- Increased frequency of access to LEO, GEO, and Deep-Space for Science measurements
- Distributed, isochronous, and field-wide measurements
- Disposable, short-term measurements in difficult regions
- Responsive, opportunistic science measurements
- “Buoy” science measurements of in-situ environments
- Alternatives to large missions
- Augmentations to large missions



Summary

- NASA's CubeSat/Nanosat Missions:
 - Can provide valuable Science in many venues:
 - BioScience and Swarm science
 - Early science comes from instrumentation that demands less of the spacecraft
 - Has Unique characteristics to enable specialized science
- NASA can use CubeSats as
 - Augments existing Science, Technology and Exploration missions
 - Alternatives to Larger missions
- NASA's Future Science exploration will include CubeSats



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QUESTIONS?



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CubeSats and Science Return



BackUp



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Ames

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O/OREOS Nanosat

Organism/Organic Exposure to Orbital Stresses

SMD Astrobiology Small Payloads Program

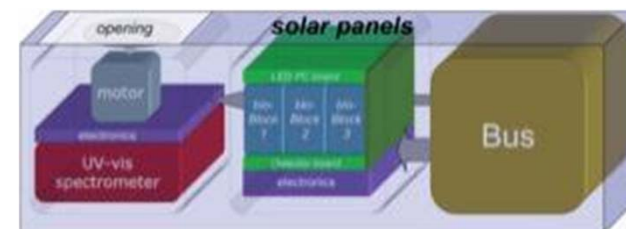
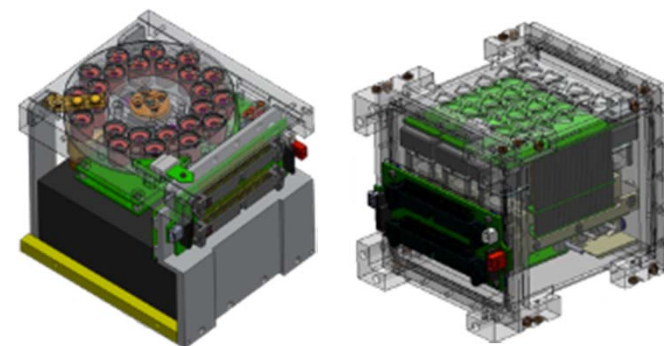
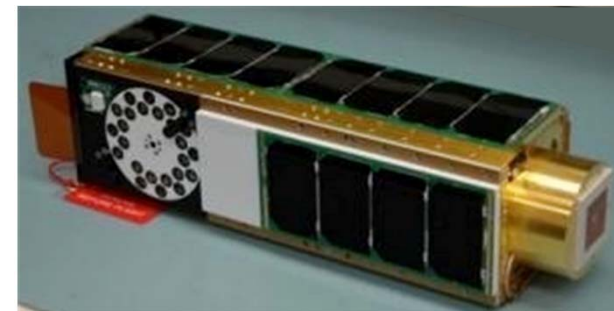
Goal: Astrobiology -- viability of microorganisms and astrobiologically relevant organics over 6-month space exposure.

Technology:

- 10x10x30 cm Nanosat Bus (3U)
- UV-Vis Spectrometer (1 cube)
- Biology growth-&-analysis system (1 cube)

Success: Launched Nov. 19, 2010. Full mission success, both payloads, May 23, 2011. 4 refereed papers published. S/C still operational FY15.

Still Operational in FY15





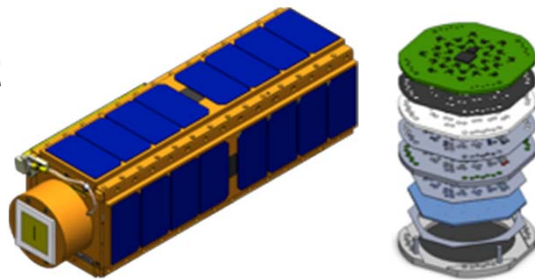
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HEOMD: Space Life and Physical Sciences

Current Space Biology Projects in Cooperation with SMD Astrobiology
Small Competed Missions of Opportunity in Astrobiology and Fundamental
Space Biology AO (SALMON 2008) – 2 selected projects *SporeSat* and
EcAMSat.

SporeSat



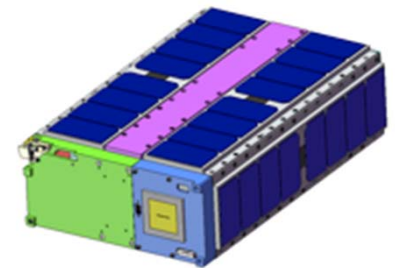
Objective:

To gain a deeper knowledge of the mechanism of cell gravity sensing by studying the activation of plant gravity sensing and electro-physical signaling in a single-cell model system (*Ceratopteris richardii*) using a “lab-on-a-chip” microsensor technology platform.

PI: Amani Salim, Purdue University
Engineering: Ames Research Center

EcAMSat

Escherichia coli
Antimicrobial Satellite



Objective:

To determine how microgravity alters antibiotic resistance of uropathogenic *Escherichia coli* (UPEC), including the role of a critical resistance gene that indicates a marked increase in UPEC antibiotic resistance

PI: A.C. Matin, Stanford
Engineering: Ames Research Center



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BioSentinal: Deep-Space Biology

Mission Objectives:

A 6U CubeSat to be launched on NASA's EM-1

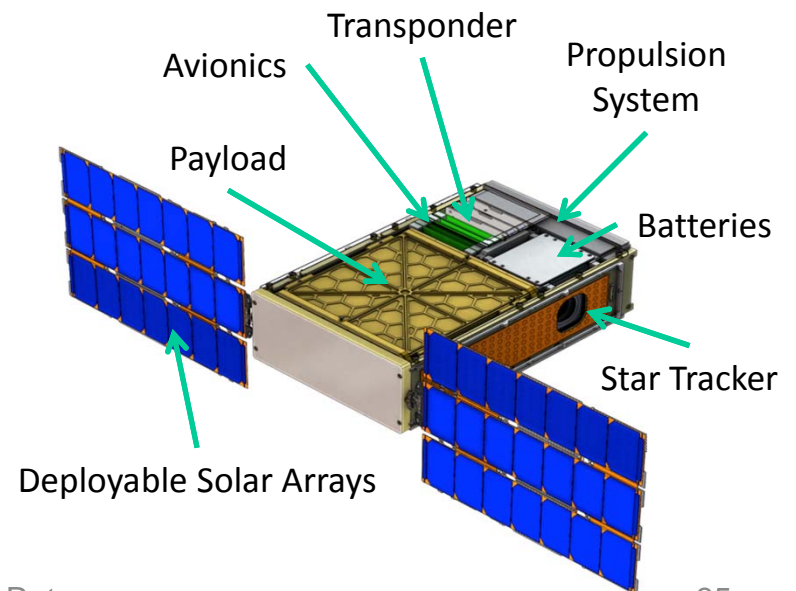
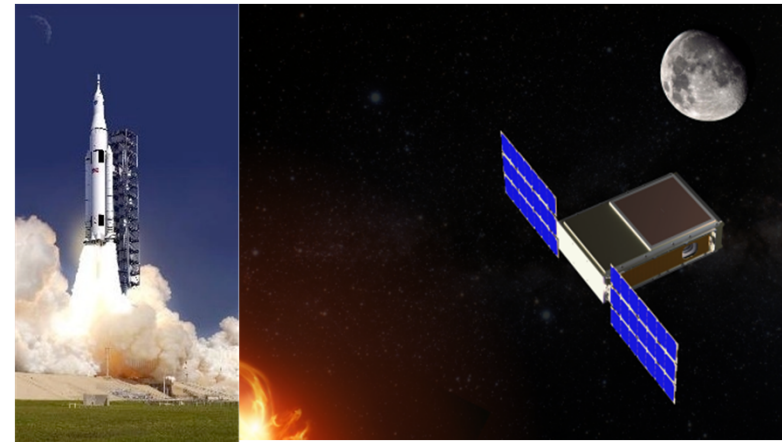
- 0.73 AU from Earth at 18 months
- Far outside the protective shield of Earth's magnetosphere

Conduct life science studies relevant to human exploration

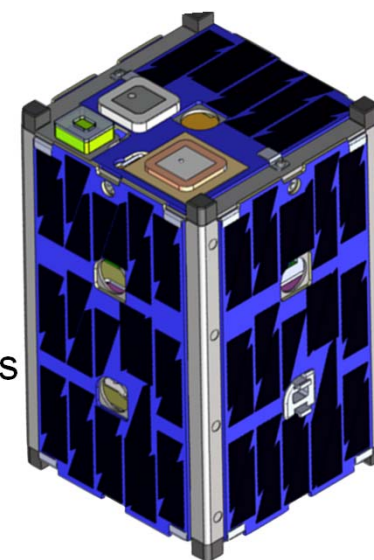
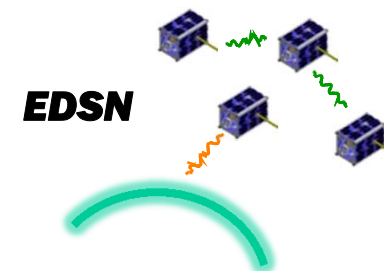
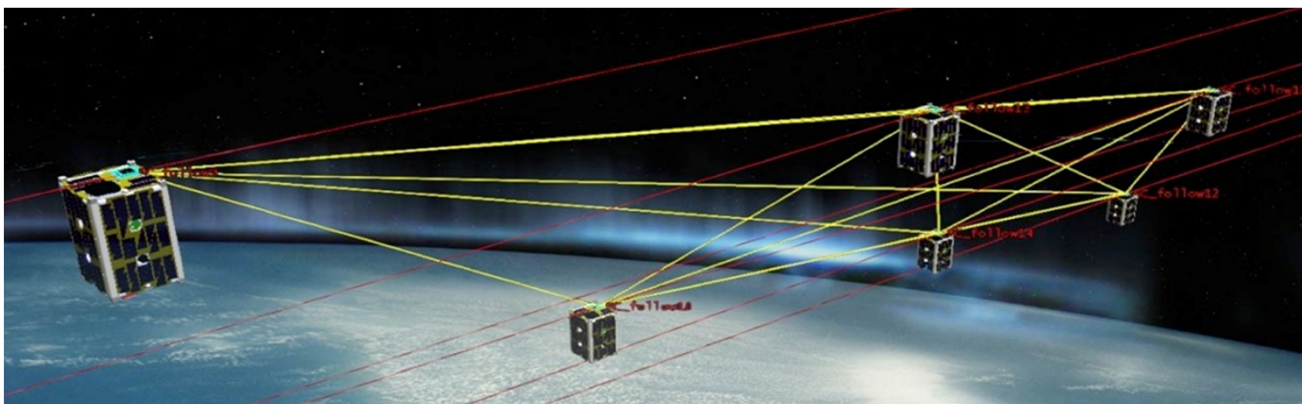
- 1st biological study beyond LEO in over 40 years
- Uses DNA double strand break frequencies to calibrate radiation damage in space
- Validate biological radiation damage models

Design payload with sensors for multiple environments

- BioSensor, LET Spectrometer, TID Dosimeter
- Instrument on ISS at similar time to EM-1 launch
- Ground controls in lab and at radiation beam facilities



EDSN: Edison Demonstration of Smallsat Networks



Nanospacecraft Technology Demonstration:

- **Novel intra-swarm comm, and dedicated downlink**
 The first true Swarm in space. Configured to allow spacecraft to talk to each other and share data, while taking time synchronous geographically dispersed payload measurements
1 spacecraft talks to Ground for the whole Swarm.
- **Multi-point space physics (radiometers)**
 Record and aggregate synchronized multi-point payload and health measurements

- NASA Ames – PM and S/C bus
- Montana State University – Instrument
- Santa Clara University – Ground Station

EDSN spacecraft is a 8x 1.5U nanosat technology mission from NASA's STMD



**October 2015
Launch**

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